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STABLE FLOATING PLATFORM. PART I. WAVE BREAKING IN DEEP WATER. PART II. ELECTROMAGNETIC ROUGHNESS OF THE OCEAN SURFACE. PART III

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UNIVERSITY OF CALIFORNIA, SAN DIEGO
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Technical Progress Report

June 30, 1973

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13. ABSTRACT

This semi-annual report reflects the technical status of projects conducted within the Advanced Ocean Engineering Laboratory at the Scripps Institution of Oceanography. These projects are: (1) Stable Floating Platform - to conceive, design, build and demonstrate the feasibility of large stable floating platforms in the open sea. (2) Wave Breaking In Deep Water - a projected two-year laboratory and field investigation of the factors controlling the breaking of mixed-frequency wave systems in deep water. (3) Electromagnetic Roughness of the Ocean Surface - utilization of radio signals scattered from the sea surface to determine the directional spectrum of ocean waves.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stable Floating Platform						
Catamaran Model, 1/8 Scale						
Major Module (barge), 1/8 Scale						
Auto-Collimator						
Wave Breaking In Deep Water						
Convergent Breaking						
Velocity Field						
Energy Budget						
Electromagnetic Roughness of the Ocean Surface						

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ADVANCED OCEAN ENGINEERING LABORATORY

TECHNICAL PROGRESS REPORT

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Part I

STABLE FLOATING PLATFORM

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Part I

STABLE FLOATING PLATFORM

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I. Project Summary

In the six month period ending June 30, 1973 a considerable amount of progress has been made in the SIO Stable Floating Platform project. Major milestones have been met. Some adjustments to the planned schedule were incorporated to pursue new avenues that appeared to have significant impact on general project objectives. One case in point was during 1/100th scale model tests. Time was taken to develop a simultaneous double target optical collimator system. The real time results together with two sources of automated wave height recording were programmed into the PDP-8E computer for analysis. The developed techniques will be documented in the final report of the Stable Floating Platform.

The final tests at sea of 1/8th scale catamaran models were conducted in early February. These included coupling, uncoupling and slamming with computer integrated recording and analysis of data.

Tests of the 1/100th scale major module/two legs complex were completed. Final analysis is in progress. The results also will be contained in the final project report.

An analysis of a number of parameters involved in the design of a large platform of "floating airport" size was completed and submitted in April (ref. a).

The major module (barge) was completed and flipped in quiet water in San Diego harbor. All major components - two legs, three upper and three lower struts - are completed. Coupling fittings are partially completed.

The final two items of the Tachmindji "Advisory Committee Report" (ref. b) will be forwarded in the very near future.

II. 1/8th Scale Catamaran Models

Final sea tests of the two 1/8th scale catamaran models were conducted in early February. The models were fully instrumented with a total of 19 sensors. These included load cells, wave height sensors, accelerometers and inclinometers. A primary objective was to test the feasibility of an on-site interface between the sensors and PDP-8E computer. The computer was located in a 8'x8'x14' Mobile Van in a support ship and received signals from the sensors through an electronic package in one catamaran model, thence via a data cable. The computer was programmed to sample each of the 19 sensors at a rate of 8 times per second, perform analog to

digital conversions and to store the digitized data on magnetic tape. Other programming permitted examination of data to assure completeness and validity.

Considering that the complete system was new and untested, the results were most gratifying. Final analysis will be reported later.

The February catamaran model operations also demonstrated that the coupling system described in reference (b) was fully operational. The ease with which numerous coupling/uncoupling evolutions were made permitted data collection/analysis during some of the evolutions towards the end of the underway period.

Since completion of the 1/8th scale catamaran operations one of the two models has been used for construction of the two legs involved in the 1/8th scale Major Module/2 leg complex. The second model will be retained for possible further use. Suitable fittings and equipment from both units were cannibalized as appropriate to be used in fitting out the new 1/8th scale model.

III. 1/100th Scale Model Tests

The 1/100th scale major module/satellite leg complex was tested in the AOEL Wave Channel during May and June. An important spin-off was the development of a double target flashing light system utilizing an auto-collimator to record target motion. One of the targets was located at the top, the other at the base of the 1/100th scale model complex of the barge and two legs. First one, then the other target was illuminated at a rate of 10 times per second. The recorded motion signals were transmitted to the computer for analysis. Simultaneously, data from two wave sensors was fed into the computer to permit correlation of target motion and wave action.

In addition to instrumented data collection runs, additional visual inspection runs were conducted at selected wave heights and periods. The detailed analysis results will be incorporated in a subsequent report. Initial conclusions are that:

a. The automated instrumentation system utilizing illuminated double targets and auto-collimator to measure target motion appears to have considerable promise as a technique for model testing in a wave channel.

b. The "first look" at results show the actual motions to be close to theoretical data previously computed.

c. No radical or unusual motions were observed.

IV. 1/8th Scale Major Module and Legs

Construction and initial fitting out of the major module (barge) was completed in June 1973 followed by initial flip tests conducted inside San Diego Harbor. Initial tests at sea were attempted but aborted because of unfavorable wave conditions. The barge is currently being modified and reballasted with additional flip tests at sea scheduled for early July.

The two legs are being constructed by modifying the legs of one of the two 1/8th scale catamaran models. Modifications are completed except for installation of blow/vent piping and fittings.

Six struts have been constructed, three upper and three lower, except for coupling fittings. The latter are partially completed.

V. Future Plans

Project objectives for the next six month period include:

a. Test of 1/8th scale major module (barge) at sea.

b. Completion of construction and rigging of the various parts of the large platform complex.

c. Coupling and uncoupling of complex in quiet water at San Diego County Reservoir at Lake San Vincente.

d. Coupling/uncoupling at sea initially without, then with, the instrumentation package.

e. Completion of all phases of evaluation.

f. Final report.

VI. References

(a) University of California, SIO AOEL Serial 72-1 of 11 April 1973.

(b) University of California, SIO Ref. #73-1, AOEL Rept. 38 of 30 March 1973 (Semi Annual Report).

Part II

WAVE BREAKING IN DEEP WATER

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Part II

WAVE BREAKING IN DEEP WATER

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I. Project Summary

This report summarizes the results of the third six months of our projected two-year laboratory investigation of deep water wave breaking under controlled and reproducible conditions.

During this period, we have continued our experiments with the breaking of steady-state wave trains in a convergent channel, concentrating on the changes in various wave parameters during growth to the breaking point and thereafter. We have reached the point of being able to describe the spectral transformations of growing waves, as reflected by increasing asymmetry, and have made some estimates of the fraction of energy lost in breaking. The latter increases markedly, with breaking intensity, but the propensity for intense breaking depends not only upon wave steepness, but also upon its rate of change. This distinction is rather subtle, but is essential to energy budget calculations, and we are continuing convergence experiments to resolve it.

Continuing analysis of fluid velocity measurements made during the preceding six months has resulted in a series of contour plots of vector velocities within individual waves at consecutive growth stages, showing the sudden development of a jet under the crest and associated skewing of iso-velocity contours deep within asymmetrical waves.

The remainder of this contract year will be devoted to experiments with analogous measurements among waves breaking as a result of wave-wave interactions in a non-convergent channel. Such interactions are thought to constitute the principal mechanism for breaking of large storm waves, and an understanding of them should provide a sound basis for the field experiments proposed under separate contract for the following two years.

II. Technical Report

1. Convergent Breaking

Our methods and procedures having been previously outlined (Refs. 1 & 2), we consider here only work subsequent to Jan. 1, 1973. Owing to other demands on the large wave channel, the convergent barrier could not be reinstalled until late February, and all data acquired during this reporting period were obtained during March and April. The intervening time was devoted to procedural improvements and modifications, and to analyzing data obtained last Fall.

Our new experiments were all conducted with steady-state wave trains preceded by a ramp function that procrastinated breaking until the first steady waves arrived at the measurement station. By adjusting paddle amplitude, the breaking point could be moved at will to almost any point in the convergence, the intensity of breaking being governed by increasing distance between the paddle and breaking point. These experiments were divided into two catagories: 'velocity field' and 'energy budget', as described below.

2. Velocity Field in Breaking Waves

The velocity field experiments were aimed at mapping the instantaneous magnitude and direction of fluid velocity at a sufficient number of points beneath breaking and near-breaking wave crests to permit detailed contour mapping of velocity isolines in an elevation-time frame. This entailed reproducing duplicate wave trains 30-40 times while the velocity probe array was lowered sequentially a centimeter or two at a time, so that the selected wave was sampled from crest to below the still water level. This procedure was repeated for both light- and heavily-breaking waves at three frequencies (0.66, 0.73, and 0.80 Hz), and triplicated for each probe elevation. Altogether, it involved some 300 data runs with a reproducible elevation accuracy of ± 1 cm, and timing to 0.03 sec to achieve the desired resolution.

Figure 1 is an example of such a contour plot for a 0.66 Hz heavily breaking wave about 60 cm high. This plot is reduced after contouring a large-scale computer printout. Significant features are the pronounced asymmetry of wave form, the formation of a high velocity jet just beneath the crest, and the general distortion of isolines so as to wrap around the jet. Peak jet velocity (280 cm/sec) slightly exceeds the local wave phase velocity (270 cm/sec). To our knowledge no previous experiments have revealed the interior structure of a breaking wave in such detail. By comparing sequential plots of this kind, we hope to see how these features develop from a relatively symmetric wave of slightly lower amplitude.

3. Energy Budget in Breaking Waves

These experiments consisted of multiple runs at the above three frequencies, between which an array of three digital wave staffs and a subsurface pressure transducer were moved through 10 measurement positions centered on the breaking point of particular waves in a 30-wave sequence. All sensors were digitally recorded at a 10 Hz sample rate, and all runs repeated for five generator amplitude settings and at two breaking intensities. Motion picture and videotape backup were provided where breaking occurred within two viewing windows in the channel side.

The object of these experiments were twofold: (1) to determine sequential changes of important wave parameters before and after breaking, such as elevation, asymmetry, wavelength, phase velocity, steepness, and harmonic content, and (2) to estimate the potential energy degraded by breaking, as functions of breaking intensity, wave height, and frequency. None of these quantities has heretofore been examined quantitatively for deep water breaking waves.

Figures 2 and 3 show representative variations of wave height (a), wave length (b), and wave steepness (c) of individual 0.73 Hz waves, as functions of distance from the wave paddle and width of the converging channel. In both figures, the sample wave was the tenth in a steady train of 40 nearly identical waves. They differ only in that the paddle stroke was slightly greater in Fig. 3, so that the wave height five meters from the paddle was about 2 cm higher. Although the growth rates and absolute breaking heights in both figures are about the same, this small amplitude increase produced extreme differences in the position and character of breaking: the initially-smaller wave broke heavily and about 3.5 m farther down the channel than the larger wave; the latter broke lightly and its subsequent decay rate was much lower.

Other wave characteristics in these figures are more subtle, but significant. In both cases, crest wavelengths* significantly exceeded trough wavelengths and both increased linearly with decreasing convergence width, showing that steepening waves become progressively more asymmetric as their crests overtake their preceeding troughs. Breaking was observed to occur when the crest wavelength exceeded the theoretical limiting wavelength for deep water waves ($\lambda_m = 1.2 \times 2\ \pi g/\omega^2$) given by Michell (Ref. 3). In both cases--as in all others so far examined--the limiting wave steepness fell somewhat below the theoretical limit (0.143). This last result is somewhat tentative, since the scatter of point groups illustrates the difficulty of exactly reproducing wave heights among repetitive data runs. This scatter appears to be due to minute differences in paddle motion, and to the generation of small transverse waves because of channel convergence. Evidently, even in a carefully controlled experiment, data must be interpreted somewhat statistically, and our final conclusions will have to be based on a great deal of data yet to be examined.

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*computed from observed phase velocity x wave period.

Much the same trend is indicated by comparing the potential energy densities for these same two waves, again as functions of travel distance and convergence width (Figs. 4 and 5). These energies were computed by squaring surface elevations at 10 Hz intervals and summing over a wavelength from trough to trough. Peak energies were again much the same at breaking, but the heavily breaking wave lost energy more rapidly after breaking, and degraded to a much lower energy level, than the gradually-breaking wave. Violently breaking waves appear to lose as much as 70 per cent of their peak potential energy.

The two curved lines in Figs. 4 and 5 indicate the expected rate of energy increase over the relevant section of the convergence if energy flux were perfectly conserved. The fact that the observed increases in potential energy density near breaking fall below these lines by 30-40 per cent cannot be accounted for by convergent reflection (at most 8 per cent) or by boundary dissipation (about 3 per cent). We tentatively conclude that there is an internal conversion of potential to kinetic energy in a wave crest near breaking. Such a transition is predicted by higher order theory for steep symmetrical waves in a homogeneous field (Refs. 4 and 5), but is not discussed for asymmetric waves. For our experiments, the transition should be directly calculable from velocity field data, and is the only way of accounting for the high-velocity jet in Fig. 1. Additionally, Fig. 6 shows two consecutive motion picture profiles of a 0.66 Hz near breaking. Here the theoretical limit phase velocity is 271 cm/sec, the observed crest velocity 288 cm/sec, and the jet velocity exceeds 300 cm/sec. While a breaking jet for a progressive wave of limiting steepness is predicted from considerations of stability only (Ref. 6), there is no specification of the magnitude of jet velocity.

Thus, while asymptotic theories for symmetrical waves give some hint of the tendencies observed in our experiments for waves approaching limiting steepness, these theories suggest that steep waves must become asymmetric. But there is no theory for asymmetric waves, and the distinction between light and heavy breaking is left open. Our results should provide a sound basis for future theoretical work on most aspects of wave breaking in deep water.

III. Future Plans

During the remaining six months of this contract, we shall continue analysis of the considerable amount of data on hand, and we have also scheduled a series of experiments with waves breaking in a non-convergent channel as a result of interactions between subcritical waves overtaking one another. We have already written a number of computer programs for the tape-

controlled wave generator, and have demonstrated that we can reproducibly generate appropriate wave fields. These we propose to observe and analyze in the same manner. We anticipate that interactive breaking will be considerably more complicated than convergent breaking, because of the many possible combinations of phase and amplitude that may result in transient instability. These we propose to approach a step at a time, starting with steady-state, bi-harmonic wave trains breaking at the antinodes of the combined wave envelope, and possibly ending up with the inversion of the Fourier spectrum for a single pulse steep enough to break violently.

As a logical extension of our present studies, we have submitted a two-year proposal to the Office of Naval Research for a field study of wave breaking in storm seas. By mounting a specially-constructed 10 m wave staff and high-rate data acquisition system on a North Sea drilling tower, we propose:

a) To make sufficiently detailed repetitive measurements of surface elevation over a representative range of sea states under storm conditions so as to fully define the upper range (95% energy) of the respective sea state spectra in the ordinary sense, and to permit correlation of these spectra with those obtained by other investigators.

b) To concurrently measure the up-sea component of water particle velocity at 10 cm vertical intervals at a 0.1 sec sample rate, so as to reasonably define the horizontal flow fields in all waves sampled, and to distinguish breaking from non-breaking waves, as well as relative breaking intensity.

c) To examine these data for breaking invariants of the type derived from our controlled laboratory breaking study, in hope of proving a basis for a more deterministic theory for sea state growth toward breaking equilibrium.

d) To cross-correlate breaking incidence and intensity with sea state, in hope of expanding present sea state prediction methods to include the statistical probability of breaking, and the range of velocities and impact forces.

IV. References

1. Van Dorn, W. G. and R. E. Davis, Wave Breaking in Deep Water, AOEL, Tech. Progress Report, June 30, 1972.

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5. Davies, T. V., "Theory of Symmetrical Waves of Finite Amplitude", Proc. Royal Soc. London, vol. 208, series A, 1951, p. 475-486.

6. Price, Roland K., "The Breaking of Water Waves", Jour. Geophys. Res., vol. 76, no. 6, Feb. 1971, p. 1576-1581.

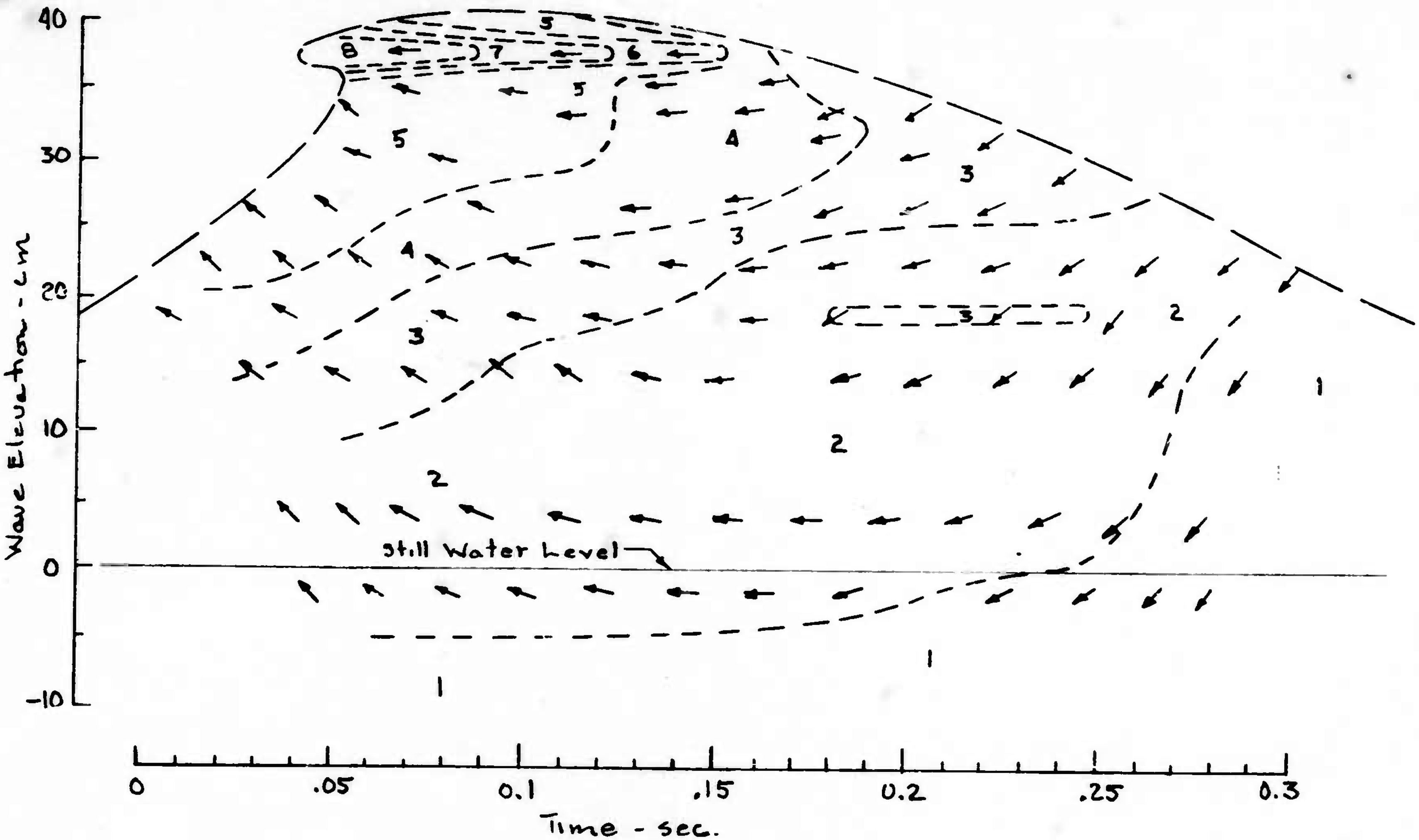

Figure 1. Composite contour plot of velocity field within a heavily breaking 0.66 Hz wave. Arrows indicate instantaneous flow direction.

Numeral	Velocity Range(cm/sec)	Numeral	Velocity Range(cm/sec)
1	60- 80	5	140-180
2	80-100	6	180-220
3	100-120	7	220-260
4	120-140	8	260-280

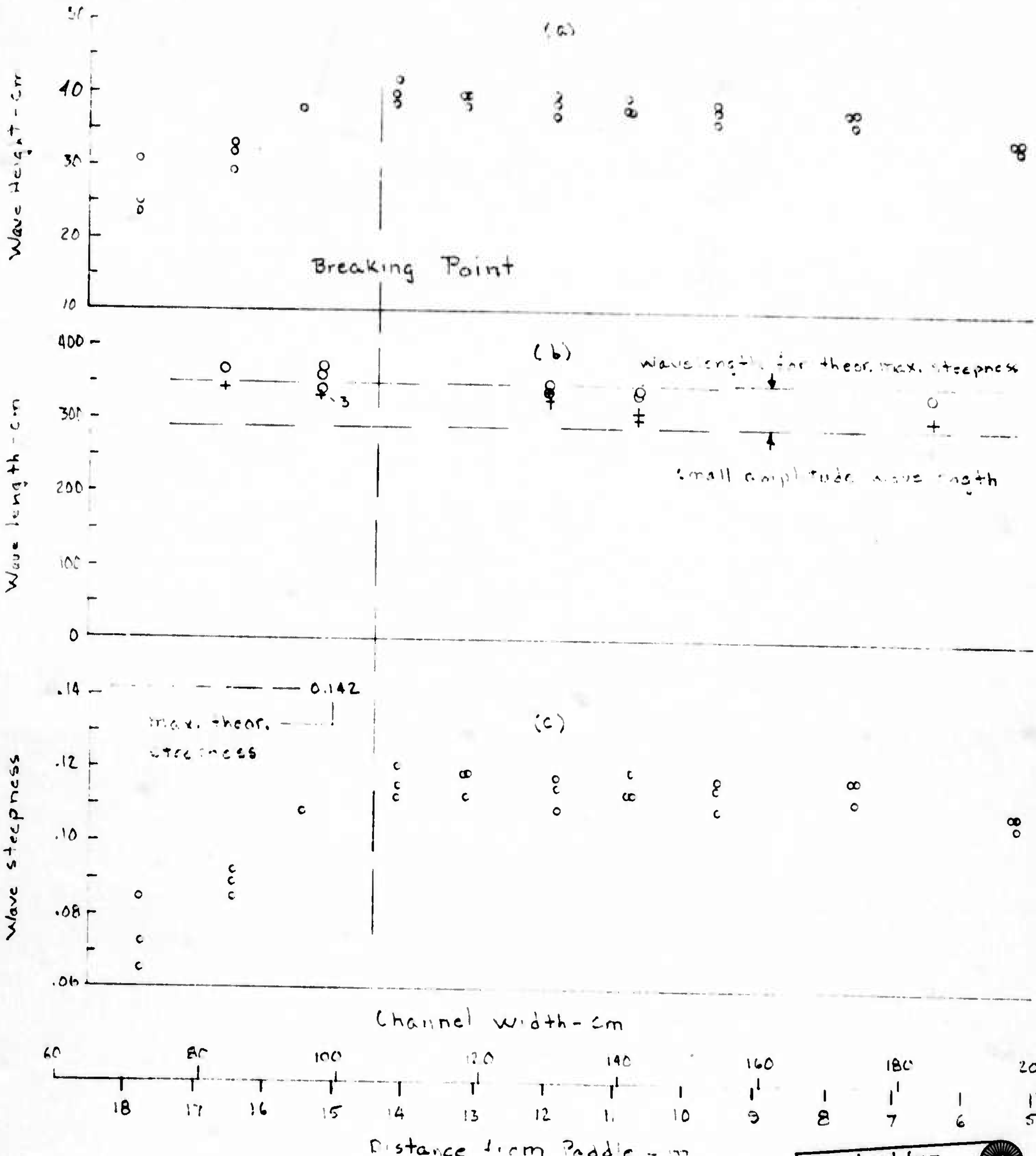

Figure 2. Variation of wave height, length, and steepness with distance along a converging channel, for a heavily breaking 0.73 Hz wave.

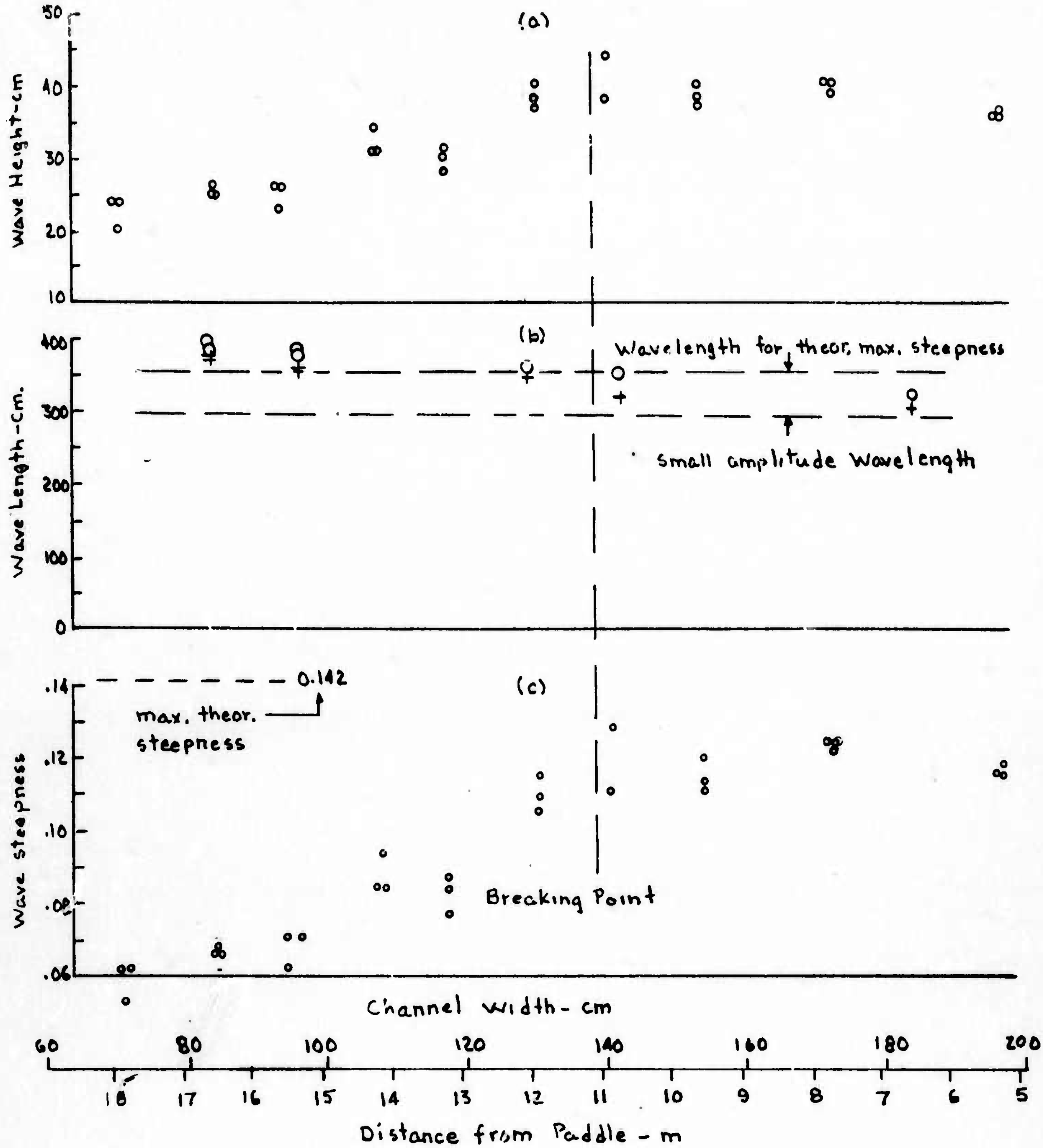

Figure 3. For conditions otherwise the same as in Figure 2, but with an initial wave height 2 cm higher, the wave breaks lightly, and 3.5 m closer to the paddle.

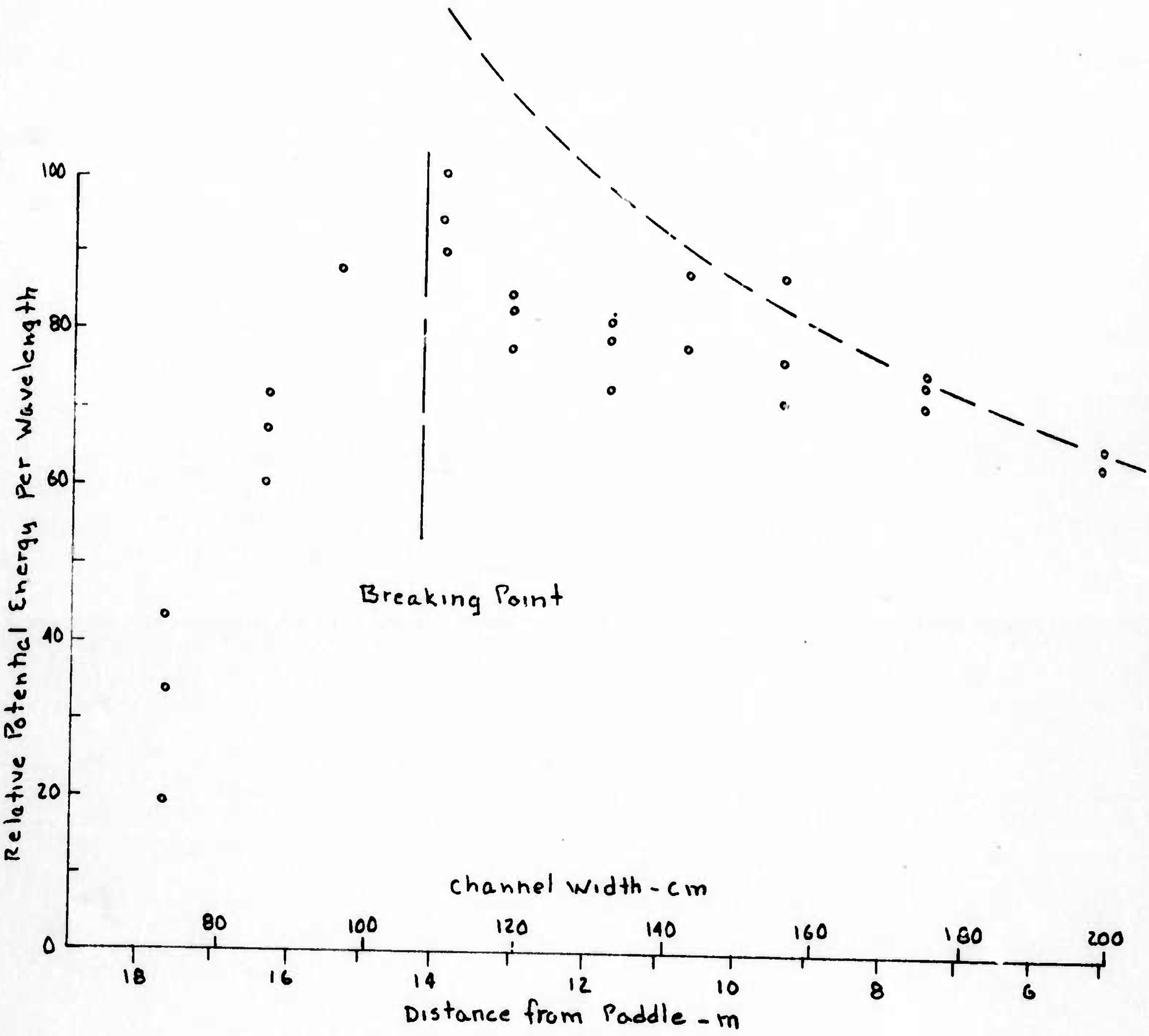

Figure 4. Variation of potential energy for conditions of Figure 2. Multiple points show variance among three data runs. Curve gives predicted variation for conservative energy flux.

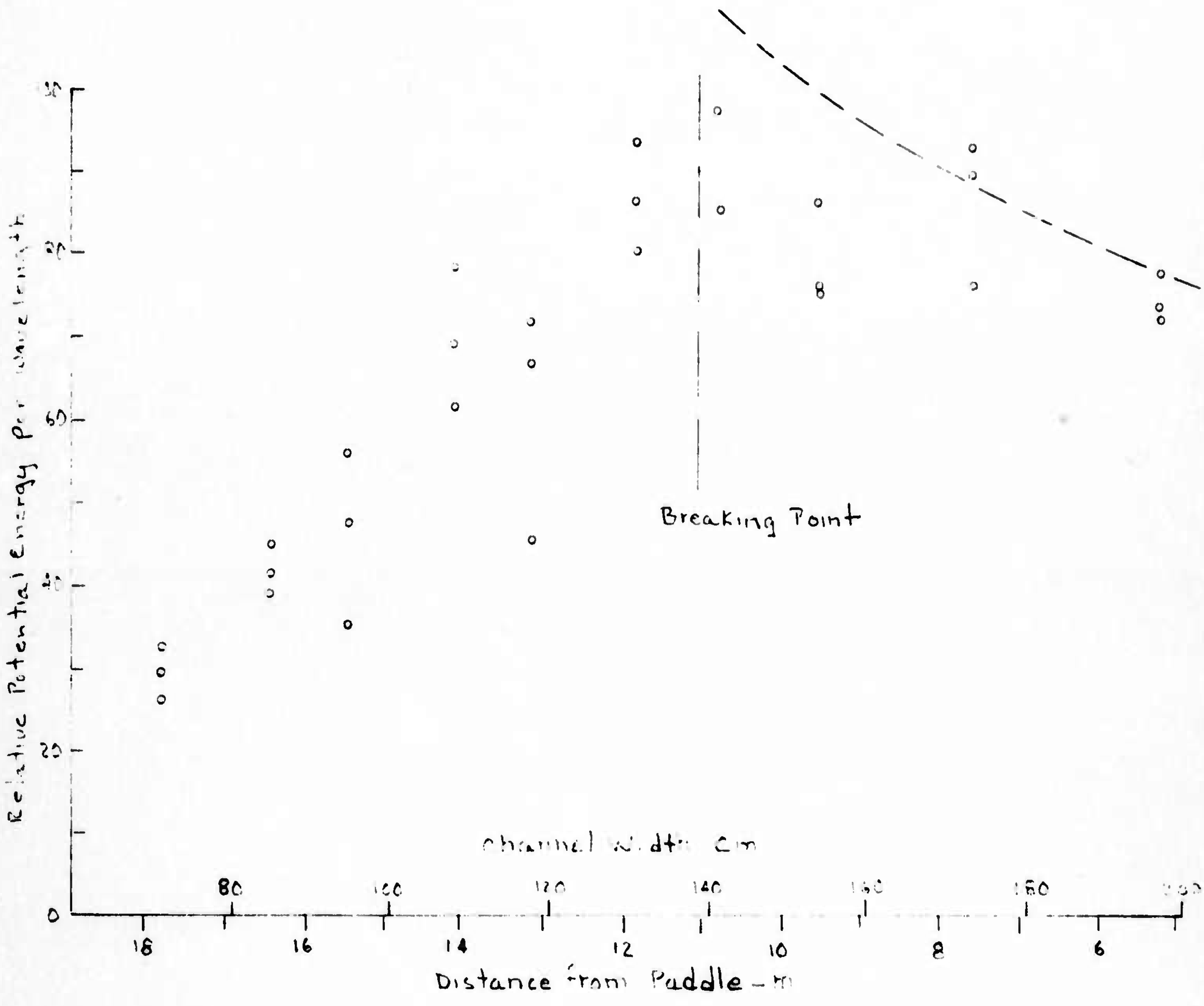

Figure 5. Variation of potential energy for conditions of Figure 3.

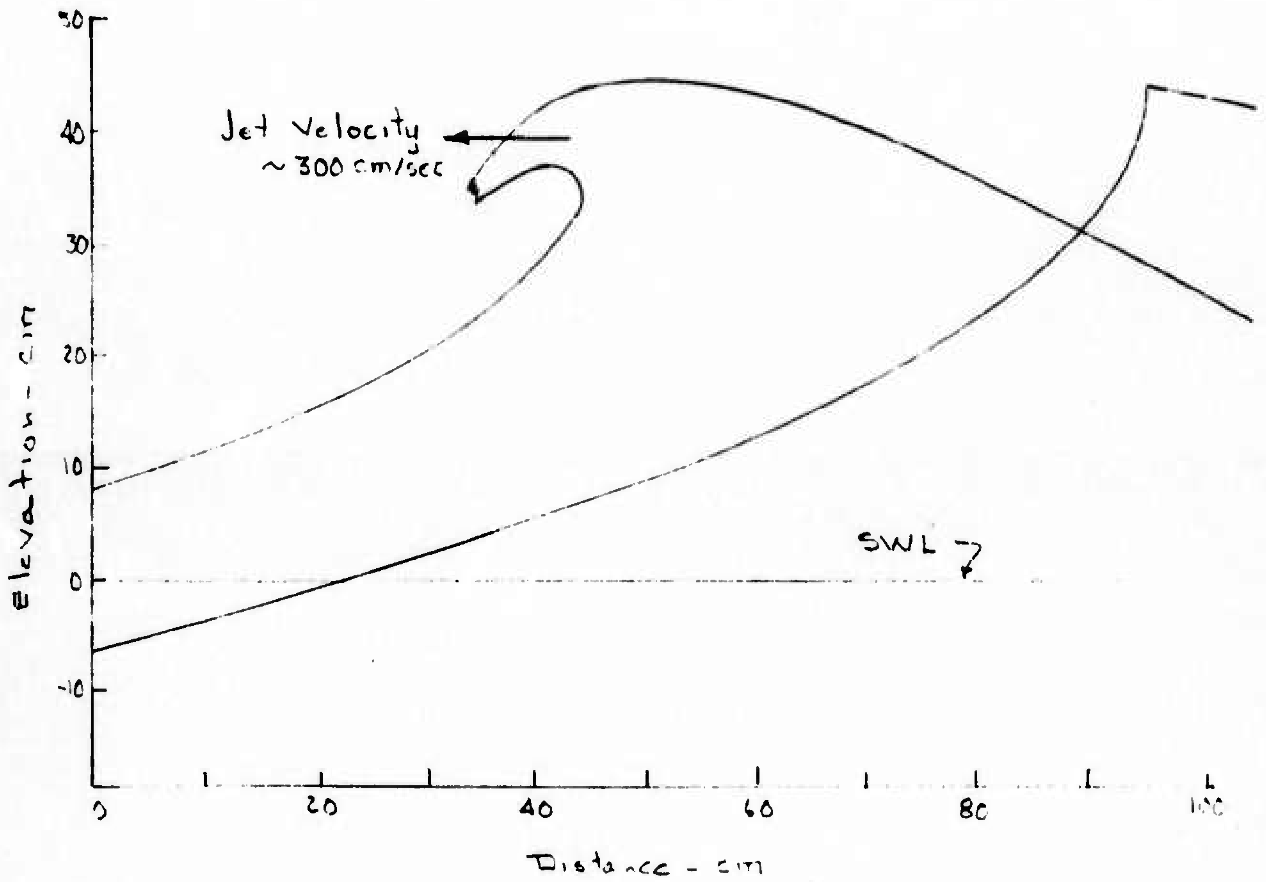

Figure 6. Photographic profiles of heavily breaking 0.66 Hz wave over time interval of 0.156 sec., showing rapid acceleration of crest to form high velocity jet.

Part III

ELECTROMAGNETIC ROUGHNESS OF THE OCEAN SURFACE

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As the "Electromagnetic Roughness of the Ocean Surface" section of ONR Contract N00014-69-A-0200-6012 terminates on August 31, 1973, a semi-annual technical report covering the period January 1, 1973 through June 30, 1973 will not be contained herein since it would have essentially been a duplicate effort, in part, of the final technical report. The final technical report for this research effort will be prepared and submitted in accordance with section F of referenced contract.